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3D Surface Mapping of Capsule Fill-Tube Assemblies used in Laser-Driven Fusion Targets

E.S. Buice, E.T. Alger[1], N.A. Antipa, S.D. Bhandarkar, T.A. Biesiada, A.D. Conder, E.G. Dzenitis, M.S. Flegel, A.V. Hamza, C.L. Heinbockel, J. Horner, M.A. Johnson, L.M. Kegelmeyer, J.S. Meyer, R.C. Montesanti, J.L. Reynolds, J.S. Taylor and P.J. Wegner
Lawrence Livermore National Laboratory, USA
[1]General Atomics, USA
esbuice@LLNL.gov

Abstract

This paper presents the development of a 3D surface mapping system used to measure the surface of a fusion target Capsule Fill-Tube Assembly (CFTA). The CFTA consists of a hollow Ge-doped plastic sphere, called a capsule, ranging in outer diameter between 2.2 mm and 2.6 mm and an attached 150 μm diameter glass-core fill-tube that tapers down to a 10 μm diameter at the capsule. The mapping system is an enabling technology to facilitate a quality assurance program and to archive 3D surface information of each capsule used in fusion ignition experiments that are currently being performed at the National Ignition Facility (NIF) [1]. The 3D Surface Mapping System is designed to locate and quantify surface features with a height of 50 nm and 300 nm in width or larger. Additionally, the system will be calibrated such that the 3D measured surface can be related to the capsule surface angular coordinate system to within 0.25 degree (1σ), which corresponds to approximately 5 μm linear error on the capsule surface.

1 3D Surface Mapping System

The 3D Surface Mapping System, shown in Figure 1, comprises seven linear and three rotation axes that are used to manipulate the Capsule Fill-Tube Assembly (CFTA) to achieve a deterministic 4π steradian inspection using a confocal microscope. The primary fixture for handling the CFTA is a vacuum wand shown in Figure 2. The fill-tube is inserted into the inner diameter of the conical tip such that the fill-tube is captured within the wand (basic functionality of the wand is described by Montesanti et.al. [2]). A second vacuum wand, the hand-off wand, will provide the capability of exposing the area initially covered by the primary wand.

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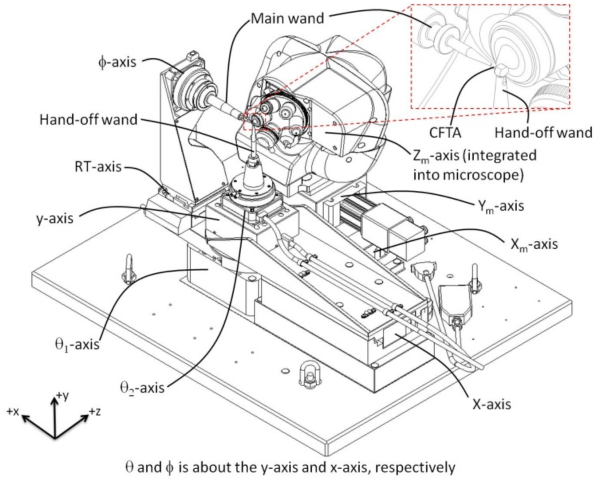

Figure 1: Overview of the 3D surface mapping system indicating motion axes and vacuum wands.

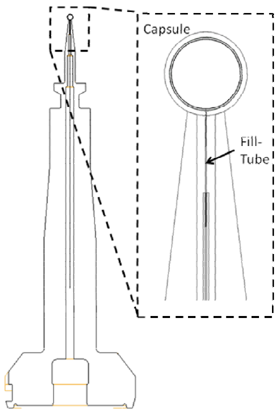

Figure 2: Primary fixture used to hold the CFTA.

1.1 Operating principle

After homing and moving the stages to its home location, the primary wand fixture is mounted to the φ-axis stage which holds the CFTA. The optical microscope is used to determine the center and surface location of the capsule. The capsule can be 'centered' to its desired location by predetermined actuation of the RT-, X_m-, Y_m- and Z_m-axes. The first image is taken with the stages at their nominal home position by performing a scan in the z-direction (radial with respect to capsule center) using the Z_m-axis from approximately 1 μm below the surface to approximately 1 μm above the surface. The next step is to rotate the ϕ-axis by a predetermined increment. The incremental step is determined by the magnification of the objective used during the measurement. Once the incremental step is performed by the ϕ-axis stage, the microscope can once again be used to determine the center of the CFTA and use the RT-axis stage (where R is radial and T is tangential in respect to the θ_1-axis) in combination with the Y_m-axis stage to position the CFTA to its 'original' location. By continuously determining the center of the CFTA the system is not only able to correct for small error motions induced by the stages and mounting misalignment of the main wand, but also automatically compensate for thermal growth of the instrument.

The ϕ-axis will continue to perform incremental steps until it has rotated 360 degrees. At this point the θ_1-axis stage will be rotated at a predetermined increment. The increments of the θ_1-axis will be performed through its travel limits of -26 to +90 degrees and at each incremental step the ϕ-axis is repeated. There will be a limit of how far the θ_1-axis can be rotated due to mechanical interference, which will require the use of the X_m-axis to make a step towards the main wand while the θ_1-axis is at the -26 degree position. Once the X_m-axis is at its new location the ϕ-axis is again rotated 360 degrees until the entire strip of images is collected.

At this point, approximately 95% of the CFTA surface has been imaged. To obtain the remainder of the 5% the CFTA is handed off from the primary wand to the hand-off wand. The hand-off is performed by moving the X-axis such that the hand-off wand is within approximately 100 μm of the capsule. At this point the RT-axes and Y-axis can be used to adjust any misalignment between the axis of the primary wand and the axis of the hand-off wand tip. Once the appropriate alignment is achieved, vacuum is turned ON at the hand-off wand while turning OFF vacuum at the main wand. This allows the CFTA to gently jump from the main wand to the hand-off wand. After the hand-off is performed the R-axis is driven approximately 2.5 mm away from the CFTA to expose the fill-tube. Once the fill-tube is exposed both the θ_1- and θ_2-axis are rotated simultaneously to -26 degrees. Once this position is achieved, the θ_2-axis continues to rotate an additional 60 degrees to bend the fill tube. During this rotation the RT-axes are also moved such that during the bending of the fill-tube minimal forces are exerted on the fill-tube capsule glue interface. When the bending of the fill tube is complete the X_m- and Y_m-axis are used to stitch multiple images together to complete the surface mapping. After completing the mapping of the CFTA around the fill-tube, the process is reversed such that the CFTA is once again held by the primary wand, which concludes the measurement of the CFTA.

2 Imaging system

A confocal microscope is used to capture the surface of the CFTA to ensure quality assurance standards are met. A spherical test sample, including deliberate surface defects and contamination, was measured to determine the capabilities of the confocal microscope. Figure 3 shows a 20x confocal image of the spherical test sample. The inset in Figure 3 is a perspective view of height data from a single particle at 100x magnification. Using a stitching algorithm, a 3D surface profile of the entire surface can be generated with the use of individual images, such as the one shown in Figure 3.

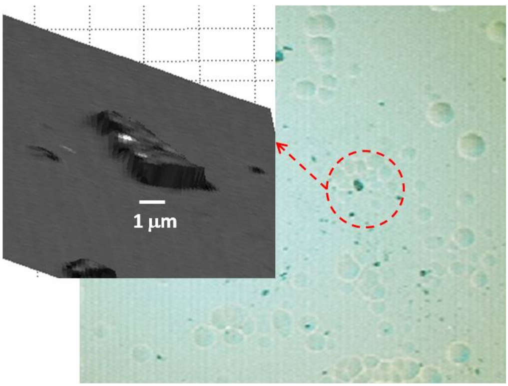

Figure 3: Image patch of a spherical test sample indicating the performance capability of the confocal microscope.

References:

[1] http://lasers.llnl.gov/

[2] Montesanti R.C., Johnson M.A., Mapoles E.R., Atkinson D.P., Hughes J.D. and Reynolds J.L., 2006, Phase-Shifting Diffraction Interferometer for Inspecting NIF Ignition-Target Shells, Proceedings of the American Society for Precision Engineering Annual Meeting, Monterey CA, USA.